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RADIOTELEGRAPHY.—*Direction determinations of atmospheric disturbances on the Isthmus of Panama.*[1] L. W. AUSTIN. Laboratory for Special Radio Transmission Research.[2]

It has long been known that atmospheric disturbances in general originate over land rather than over the ocean. It is also known that the sources of the tropical disturbances seem to follow the sun in its changing path between the northern and southern hemispheres.[3] It was therefore to be expected that during the winter in Panama, (10° north), the atmospheric disturbances would come chiefly from the mainland of South America, while in summer they might be expected to come from the direction of Central America and Mexico. In addition, during the rainy season, it could be assumed that there would be a considerable amount of local disturbance generated in the low mountain chain which forms the backbone of the isthmus. It was not known, however, whether these local disturbances would outweigh those coming from the larger land masses.

During February and March, 1925, I made directional observations on atmospheric disturbances at frequencies of 21.4 and 15 kc. (14,000 and 20,000 m.) in the U. S. Naval radio receiving stations at Balboa and Colon, at the two ends of the Panama Canal. The measurements were afterward continued by the personnel of the two stations.

The method used in the measurements was first described in 1920.[4] The apparatus shown in the figure, consisted of an 8 ft. (2.44 m.) coil antenna with 48 turns, which was combined with a small single wire

[1] Received May 5, 1926. Published by permission of the Director of the National Bureau of Standards of the Department of Commerce.

[2] Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy.

[3] DEGROOT, Proc. I. R. E., 5: 75. 1917. GOLDSCHMIDT and BRAILLARD, La T. S. F. (Congo Belge), HAYEZ (Bruxelles) 1920. AUSTIN, Journ. Franklin Inst. 191: 619. 1921. ROUND, ECKERSLEY, TREMELLEN & LUNNON, Journ. I. E. E. (London), 63: 62. 1925.

[4] AUSTIN. Journ. Franklin Inst. 191: 619. 1921.

antenna to form a unidirectional receiving combination. In the measurements the general direction was first found by rotating the coil and adjusting the antenna coupling and resistances until the disturbance maximum was obtained with the antenna reversing switch

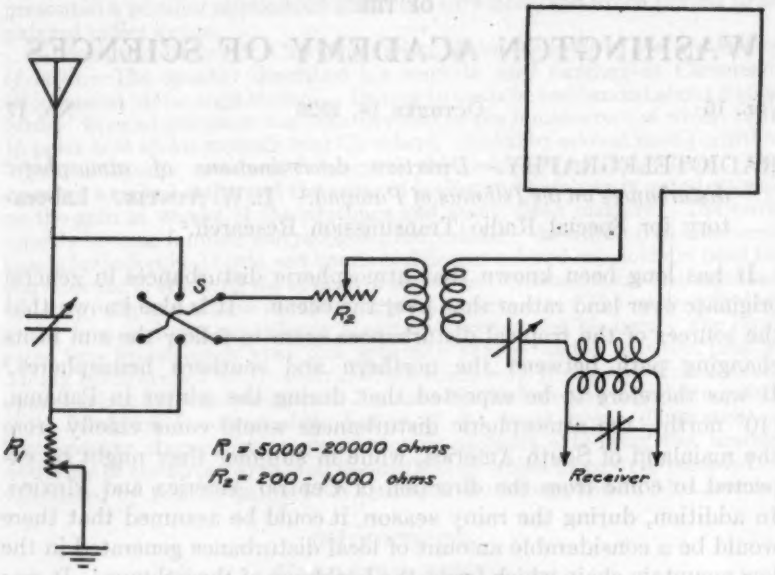

Fig. 1.—Diagram of directional receiving circuit

S thrown in one direction, and the minimum when it was thrown in the other. The absolute direction in which signals were strengthened with the switch in a certain position was determined by observations on a transmitting station in a known direction. When the general direction had been determined, the coil was turned approximately at right angles to the indicated disturbance direction; the switch S was then rapidly reversed, the coil being at the same time slowly moved until the position was found in which the sound of the disturbances in the telephones was of the same intensity with the switch in its two positions. In general there were a certain number of degrees on the coil scale over which the sound equality was maintained. The center of this zone of equality was the scale reading for which the coil was at right angles to the average disturbance direction, since in this position the coil was inactive, the whole reception being from the antenna. By this method good readings can be obtained when no direction at all can be observed on the coil antenna alone.

Table 1 shows the results of the observations from February to November, 1925. Those taken from February to the end of June were made by observers who had received personal instruction in the method of measurement and are considered more reliable than those taken later. Owing to changes in the personnel of the stations, the work was apparently entirely interrupted during July and August. During the months in which accurate measurements were generally possible, the bearings in the table are given in degrees. During the more disturbed periods the directions are only roughly indicated.

TABLE 1.—DIRECTION OF ATMOSPHERIC DISTURBANCES AT BALBOA AND COLON

	BALBOA			COLON		
		Number of observations			Number of observations	
Feb.	3 p.m.	10	All (120°–130°)[b]	—	—	—
March	10 a.m.	—	—	10 a.m.	9	All (120°–130°)[b]
	3 p.m.	25	All (125°–135°)	3 p.m.	9	All (130°–140°)
	10 p.m.	—	—	10 p.m.	9	All (120°–140°)
April	10 a.m.	7	7 NB[a]	10 a.m.	28	All (120°–145°)
	3 p.m.	29	20 NB, 7 SE, 1N, 1E	3 p.m.	25	All (130°–145°)
	10 p.m.	7	5 NB, 2N	10 p.m.	23	All (120°–140°)
May	10 a.m.	9	4 NB, 5 (NW–N)	10 a.m.	16	2 NB, 14 SE
	3 p.m.	31	15 NB, 15(NW–N), 1 NE	3 p.m.	13	2 NB, 11 SE
	10 p.m.	9	8 NB, 1 NE	10 p.m.	3	3 SE
June	10 a.m.	9	3 NB, 6N	10 a.m.	15	All SE
	3 p.m.	30	5 NB, 25 N	3 p.m.	14	All SE
	10 p.m.	9	9 NB	10 p.m.	4	All SE
	No observations in July and August					
Sept.	—	—	—	10 a.m.	30	1 NB, 29 SE
	—	—	—	3 p.m.	30	1 NB, 28 SE, 1S
	—	—	—	—	—	—
Oct.	10 a.m.	31	26(NW–NE), 5 SE	10 a.m.	31	All (130°–140°)
	3 p.m.	31	3 NB, 23(NW–NE), 5 SE	3 p.m.	31	All (130°–145°)
	10 p.m.	31	25 NB, 5(W–N), 1SE	—	—	—
Nov.	10 a.m.	30	19(E–SE), 8(NW–NE), 3(S–W)	10 a.m.	30	All (135°–140°)
	3 p.m.	30	1 NB, 20(SE–S), 3(SW–W), 6(NW–NE)	3 p.m.	30	All (130°–145°)
	10 p.m.	15	13 NB, 1SE, 1NE	—	—	—

[a] NB = no definite bearings.

[b] The angles are measured clockwise from north.

The data obtained seem to warrant the following conclusions:

1. During the dry season, probably from January 15 to April 1, the atmospheric disturbances both at Balboa and Colon come almost entirely from the South American continent, from the direction of the high Andes in northern Colombia.

2. When the dry season comes to an end and local storms begin to appear, the local disturbances from the low mountains of the isthmus begin to be prominent. This shifts the prevailing direction at Balboa at times from the southeast to the north, but has little effect on the direction at Colon since the mountains containing the local centers of disturbance here lie to the south and east, or roughly in the direction of the disturbance sources in Colombia.

3. In midsummer, while there is probably much disturbance from Central America and Mexico, the local disturbances from the isthmus mask this to such an extent that the prevailing direction at Colon continues roughly southeast, while at Balboa the distant and local disturbances unite to give a northerly or northwesterly direction.

4. The observations further indicate that from northern sending stations, Balboa and Colon should give nearly equally good unidirectional reception in the dry season, but during the rest of the year, where the disturbance conditions are more troublesome, Colon should have considerable advantage over Balboa.

GEOLOGY.—*Major features in the geology of the Atlantic and Gulf Coastal Plain.*[1] L. W. STEPHENSON, U. S. Geological Survey.

GEOGRAPHIC EXTENT AND TOPOGRAPHY

The Atlantic and Gulf Coastal Plain is a sharply defined geologic unit, and a somewhat less sharply defined physiographic unit, throughout most of its extent in the United States. The length of the plain from Cape Cod, Mass., to the Rio Grande is in round numbers 2,000 miles. The Atlantic portion of the plain (exclusive of Florida) is much narrower than the Gulf portion, the former averaging about 100 miles in breadth and the latter (exclusive of the Mississippi Valley) averaging about 250 miles. The Mississippi Valley from the Delta to to Cairo is about 570 miles long and the Peninsula of Florida about 400 miles long. This vast so-called plain rises from sea level on the coast to a maximum of somewhat more than a thousand feet in parts of Texas, and there is in general a rise in the altitude of the inner margin of the plain from a little more than 100 feet in places on Cape Cod

[1] Presidental address read before the Geological Society of Washington, December 9, 1925. Published by permission of the Director, U. S. Geological Survey. Received September 18, 1926.

(disregarding hills of glacial upthrust which are nearly 300 feet high) in the northeast to over a thousand feet in Texas.

Beyond the Rio Grande in Mexico the country that can properly be classed as Coastal Plain narrows rapidly toward the south, the inner margin approaching to within a few miles of the coast, and from the vicinity of Tampico southward to Yucatan is represented only by narrow areas bordering the coast. In Yucatan the plain broadens out again to large proportions, practically the whole of the peninsula presenting a coastal plain aspect. In eastern Mexico, however, no serious attempt has as yet been made to determine the exact boundaries of the areas that should be classed as coastal plain.

Although we ordinarily think of the Coastal Plain as ending at the coast, it does not in reality end there but extends out under the sea to the edge of the Continental Shelf, the position of which is shown on the map. In other words, a part of the Coastal Plain is submerged to maximum depths of about 600 feet. Off the New England coast the entire Coastal Plain goes out to sea and is completely submerged. At the edge of the Continental Shelf the submerged surface plunges steeply to the abysmal depths of the ocean.

Although the term "coastal plain" seems to suggest a region of level topographic aspect, the Atlantic and Gulf Coastal Plain is by no means a featureless plain. The province does present extensive tracts of nearly level plain, but other extensive areas range from rolling to sharply hilly. Examples of the former are the broad marine terrace plains which are more or less clearly developed and preserved from the Eastern Shore of Maryland southward to Florida, and the alluvial terrace plains of all the larger streams crossing the Coastal Plain, the finest and broadest examples of which are in the valley of Mississippi River. The hilly topography occurs in the higher, dissected, inter-stream areas, especially along the inner margin of the Coastal Plain from the Carolinas southwestward to Mississippi Valley, and beyond the Mississippi in Arkansas, Louisiana, and Texas. Locally there are rough forest-covered tracts of dissected upland of unbelievable wildness, several examples of which are: the Cretaceous sand hills in Cumberland and Scotland counties, North Carolina, and similar hills in Marlboro, Chesterfield and Kershaw counties, South Carolina; the Cretaceous hills along the inner margin of the Coastal Plain in Alabama; the Tombigbee River hills, and the hills of the Pontotoc Ridge, in northern Mississippi; and the Tertiary hills of Anderson and Cherokee counties, Texas.

CHARACTER AND FORM OF SEDIMENTS

The Coastal Plain is underlain by a series of sedimentary formations composed of sands, clays, marls, limestones, and chalks, and subordinately of gravels, diatomaceous earths, water-laid volcanic materials, and common salt in the form of plugs or so-called salt domes. Locally in Arkansas and Texas the sediments have been cut by intrusive igneous rocks. The thick accumulations of chalk and limestone are restricted to the south Atlantic and Gulf Coastal Plain. These various materials are mainly unconsolidated or only partly consolidated, though some indurated layers occur interbedded with the softer beds, and they range in age from Lower Cretaceous to Recent. They rest upon a basement of much older consolidated rocks which range in age from pre-Cambrian to Triassic. The different kinds of materials do not form separate uniform sheets extending throughout the entire length of the Atlantic and Gulf Coastal Plain, for the sediments laid down at any given time differed from place to place, and the conditions of sedimentation constantly shifted from time to time. Briefly stated, this means that no two columnar sections, unless closely adjacent to each other, are identical in lithologic succession. This diversity in the succession of formations in different sections is one of the chief difficulties encountered by the stratigrapher and paleontologist in determining the age and stratigraphic relationships of the formations.

Viewed as a whole the sediments of the Coastal Plain form a wedge-shaped mass along the eastern border of the continent, with the blade of the wedge represented by the thin feather edge along the inner margin of the plain. The thick end of the wedge along the coast ranges in thickness from a measured minimum of 1,540 feet at the mouth of Cape Fear River in North Carolina, to an unknown maximum probably beneath the Mississippi Delta in southern Louisiana, which may reach 10,000 feet or more. A well 5,283 feet deep, slightly more than a mile, near Pascagoula in southern Mississippi, and one 6,027 feet deep near Lockport in southwestern Louisiana, may not have penetrated half the full thickness of the sediments, though this is conjectural. The form of this wedge of sediments is extremely attenuated in cross section, far more so than we ordinarily conceive of, due to the fact that most of its published graphic cross-sections are necessarily exaggerated in the vertical scale anywhere from 10 to 50 times. To get a true picture of such a cross-section one need only plot it to its true scale. If, for example, we draw a section across the Coastal Plain in the Cape Fear region of North Carolina, where the width of the plain is about

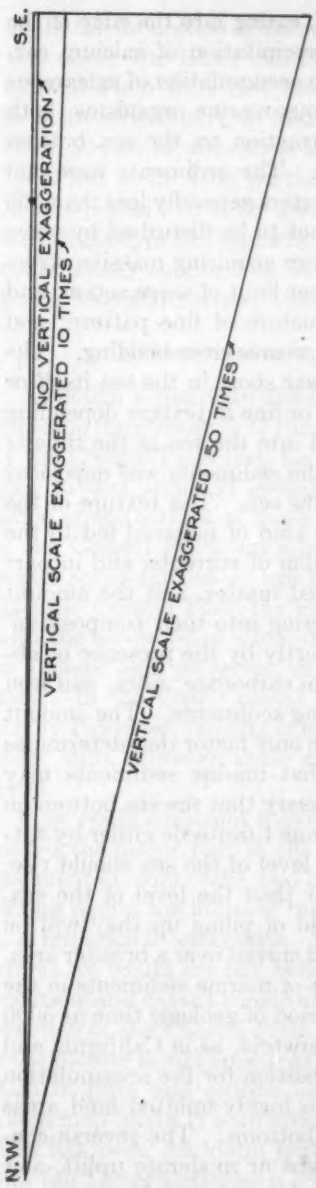

FIG. 1.—Ideal section across the Atlantic Coastal Plain showing the greatly attenuated form of the wedge of Coastal Plain sediments. The section is 100 miles long and increases in thickness from a feather edge at the left to 1,500 feet at the right.

100 miles and the thickness of the sediments at the coast is 1,540 feet, taking the length of the section as 10 feet, its coastward end would be only about a third of an inch thick. (See fig. 1.) In the Mississippi Valley, where the width of the Coastal Plain from north to south is 570 miles, if we assume a thickness of sediments at the mouth of Mississippi River of 10,000 feet, the thickness of a section 10 feet long would be only two-fifths of an inch at the Delta end. With a wedge of sediments so extremely thin as this, only relatively slight crustal movements are required to account for the known tilting and warping.

The sediments of the Coastal Plain do not end at the coast, but extend out under the sea, and if the basement surface on which they rest continues to slope uniformly the mass of the sediments must increase in thickness at least as far as the edge of the Continental Shelf, beyond which they should thin out rapidly as they merge into the oozes of the ocean depths.

ORIGIN OF THE SEDIMENTS

A very large part of the sediments of the Coastal Plain was brought into the sea by streams entering from adjacent land areas, and was derived from sedimentary and igneous rocks ranging in age from pre-Cambrian to Triassic. Lesser portions were derived partly by the

direct action of the waves of the sea itself, eating into the edge of the land along the shores, partly from the precipitation of calcium carbonate from the sea water, partly from the accumulation of calcareous and siliceous shells and skeletons of various marine organisms, both small and large, and partly from the formation on the sea bottom of the iron potassium silicate, glauconite. The sediments were laid down on the Continental Shelf in marine waters generally less than 100 fathoms deep, some in water so deep as not to be disturbed by wave action during their deposition, and therefore acquiring massive structure; some in shallower water near the lower limit of wave action, and consequently exhibiting cross-bedded structure of fine pattern; and some in water so shallow as to show strong, coarse cross-bedding. The latter were for the most part laid down near shore in the sea itself or in bays and lagoons, and are either coarse or fine in texture depending upon the character of the material carried into the sea at the time of their formation. A subordinate part of the sediments was deposited on river flood plains closely adjacent to the sea. The texture of the sediments was determined in part by the kind of material fed to the sea, in part by the strength and distribution of currents, and in part by the proportional amount of precipitated matter, and the amount and character of the organic remains entering into their composition. The degree of hardness was determined partly by the presence or absence of cementing matter, such as calcium carbonate, silica, and iron oxide, and partly by the weight of overlying sediments. The amount of the available material is by no means the only factor that determines the thickness of sediments. In order that marine sediments may continue to increase in thickness it is necessary that the sea bottom on which they are accumulating should continue to subside either by tilting or by direct downsinking, or that the level of the sea should rise, for these sediments cannot pile up higher than the level of the sea. Upon reaching nearly to sea level, instead of piling up they will be carried farther seaward by the currents and spread over a broader area. This is why a thickness of 100 or 500 feet of marine sediments in the Coastal Plain may represent as great a period of geologic time as 5000 or 10,000 feet in certain other parts of the world, as in California and in parts of South America. The ideal condition for the accumulation of great thicknesses of marine sediments is highly uplifted land areas closely adjacent to deeply subsiding sea bottoms. The reverse conditions, in which land areas undergo slight or moderate uplift, and adjacent sea bottoms sink slowly and to only moderate depths, result

in the accumulation of formations of thin to moderate thickness. It was under the latter conditions that most of the formations of the Coastal Plain were laid down, and the minimum thickness is found in the northern part, in Maryland, Delaware, and New Jersey. Here 25 or 50 feet of sediments may represent the time interval of 500 or 1,000 feet in the Gulf portion, where the maximum thicknesses occur. It may perhaps be fairly assumed that the greatest thicknesses exist in the Mississippi Embayment where an abundance of material has been continuously supplied by Mississippi River and its tributaries during Cretaceous and Tertiary time, and where subsidence has been greatest.

GEOLOGIC HISTORY AS EXPRESSED IN THE MAP

Although a complete history of the Coastal Plain would include in its scope the formation of the basement rocks upon which the sediments of the Coastal Plain rest, for the purposes of this paper I will go back only to that period of geologic time immediately preceding the deposition of the earliest of these sediments. In early Cretaceous time all of the Coastal Plain was a land area undergoing erosion, and the exposed rocks ranged in age from pre-Cambrian to Triassic. In the Atlantic Coastal Plain the rocks were pre-Cambrian crystalline rocks with the exception of a few small areas of land-laid sedimentary rocks of Triassic age, preserved in down-faulted basins within the crystallines. In the Gulf Coastal Plain the rocks were, so far as known, chiefly Paleozoic, ranging in age within that era from Cambrian to Permian, with, however, some areas of ancient pre-Cambrian crystalline rocks.

If we could construct a moving picture film of the events that have played the major part in the upbuilding of the Coastal Plain on this basement of older rocks, and could speed up that film so as to bring the picture within the limits of the present hour, we would observe the sea in a remarkable succession of advances and retreats, and after each retreat we would see left behind layers of sediment of greater or less thickness and extent constituting one of the contributions to the construction of the Coastal Plain. The sum total of these contributions, as the picture would appear at the end of the reel, would be the Coastal Plain in form and outline as we see it today. The accompanying sketch map (plate 1) is an attempt to show graphically how the Coastal Plain has been gradually built up during the time that has elapsed from the Lower Cretaceous epoch to the present.

The lines numbered from 1 to 11 show the approximate position of the

present inner, or landward, edges of the deposits that were laid down during the successive geologic epochs and periods, and it will be observed that in general, but with certain exceptions, the lines bearing the successively higher numbers occupy positions successively nearer the present coast. The deposits of each period formerly extended farther inland than their present landward limit, erosion having bevelled off their exposed edges for undetermined distances seaward from their original landward limit, in places doubtless amounting to several miles. As the width of the eroded belts varies greatly with respect to the deposits of the different periods, and also from place to place along the linear extent of the outcrop of the deposits of any period, it is not possible to show the original inner limits of the deposits. It will be observed that in places the lines marking the landward limits of the younger formations sweep inward obliquely across those marking the landward limits of the older formations, and these are the exceptions to which reference was made above, where transverse warping caused the sea to transgress farther inland than would have been the case had there been no such differential warping. Some of the more important features that are brought out by these lines are explained below.

Line 1.—This line shows the inner edge of Lower Cretaceous marine deposits (Comanche series) in the western Gulf region, and the inner edge of Lower Cretaceous continental deposits (Potomac group) in the Chesapeake and Delaware Bay region. No Lower Cretaceous deposits of marine origin are known east of Mississippi River though they may be present, deeply buried beneath the overlying younger sediments in parts of the eastern Gulf and Atlantic Coastal Plain not yet reached by the drill. The Lower Cretaceous sea submerged the western Gulf region, but so far as we know, did not submerge the eastern Gulf nor the Atlantic Coast region. In the western Gulf region the submergence was not restricted to the Coastal Plain, but spread far to the northwestward up the valley of the Rio Grande, and far to the westward, southwestward, and southward, covering nearly all of what is now the high Mesa Central of Mexico. The continental deposits of the Potomac group in the north Atlantic Coastal Plain were laid down on a low plain presumably bordering the coast of that time, though it has not been demonstrated that the strand line was any farther inland then than it is at the present time. Following the deposition of the Comanche series in a sea which covered most of the western Gulf region and most of Mexico, there was an uplift of the land which brought the submerged region above sea level and subjected it to erosion. Thus we have in Texas, Oklahoma, and Arkansas, an unconformity between the Comanche series and the overlying Gulf series.

Line 2.—This line shows the inner edge of the Upper Cretaceous deposits (Gulf series), including marine and non-marine sediments. The Atlantic and Gulf Coastal Plain tilted seaward, allowing the ocean waters to spread over most of the Coastal Plain from southern New England to Mexico. In Mexico the sea extended west of the present Coastal Plain, even encroaching

PLATE 1.—Map showing outcrop of the base of deposits of diffe
Plain. The Coastal Plain extends from the coast inland to the
by the successive additions of sediment during Cretaceous, Te
anticlinal and synclinal warping.

nits of different ages, i.e., the inner or landward edge of these deposits, in the Atlantic and Gulf Coastal nd to the border of the cross-lined area. The series of lines shows how the Coastal Plain was formed aceous, Tertiary, and Quaternary time. The heavy broken transverse lines indicate axes of broad

in places on the eastern border of what is now the Mesa Central, but probably most of central and western Mexico remained above the sea. This submergence, if restricted in its extent in Mexico, was far more extensive in the west-central and northwestern parts of the continent than the preceding Comanche submergence. An area of vast extent embracing the Great Plains and Rocky Mountain regions of the United States and Canada, was downwarped allowing the waters of the Gulf to spread inland through what is now the Rio Grande Valley region, forming a great epicontinental sea which probably extended northward entirely across the continent connecting with the waters of the Arctic Ocean. In the Coastal Plain itself the great geosynclinal valley known as the Mississippi Embayment had its initial downwarping allowing the sea to encroach northward in the form of a deep embayment having its head at the southern extremity of Illinois. During the deposition of the Upper Cretaceous sediments in and along the borders of the ocean of that period there were oscillations and warpings of the land with respect to sea level which caused minor retreats and advances of the strand line, and each such retreat is marked in the sediments by an unconformity of relatively short time significance, but at the close of the period there was a general continental uplift which freed the land of its flood of ocean waters and forced the strand line oceanward perhaps as far as the edge of the Continental Shelf. Erosion throughout the extent of the newly emerged surface produced the regional unconformity which separates the Upper Cretaceous from the overlying Eocene sediments.

Line 3.—The inner edge of the oldest Eocene deposits, those of the Midway group, is shown by line 3. The Midway sea was much more restricted in its extent than the preceding Upper Cretaceous sea; it did not cover all of western Texas and, so far as known, none except the extreme southern portion of the Atlantic Coastal Plain; it did, however, sweep northward to the head of the Mississippi Embayment, and in Georgia reached almost to the inner edge of the Coastal Plain. In parts of the Gulf region there is an unconformity between the deposits of the Midway group and those of the overlying Wilcox group, and where present this break marks a retreat of the sea.

Line 4.—This line shows the inner edge of the deposits of Wilcox Eocene age, which overlie the Midway. The line lies just a little nearer the Coast than Line 3. It extends to the head of the Mississippi Embayment but the Wilcox sea did not spread this far to the northward for the deposits in the northern part of the Embayment are of non-marine origin, probably having been laid down on the flood plain of an ancient Mississippi River, or perhaps in part as delta deposits at the mouth of the same river. In Georgia the Wilcox deposits are overlapped and concealed by younger deposits (see Line 7), but they reappear again in a small area in the eastern part of South Carolina. Several remnants of shallow marine deposits of Wilcox age (identified by Dr. Wythe Cooke) occur on the upland resting on the Cretaceous near the inner edge of the Coastal Plain in North Carolina, and one such

remnant (also identified by Cooke) occurs resting on crystalline basement rocks a few miles east of Raleigh. Whether these remnants indicate a complete transgression of the sea over eastern North Carolina, or were laid down in a restricted embayment is not known. If, however, Wilcox deposits were ever laid down over all of the North Carolina Coastal Plain they were later largely removed by erosion, for they are wanting over most of the area, and younger deposits of Jackson Eocene age, rest directly upon the Cretaceous in the vicinity of Wilmington. No attempt has been made to represent on the map the shore line of the sea in which these remnants were laid down. The Eocene is completely overlapped by upper Miocene deposits in the northern part of the North Carolina and southern Virginia Coastal Plain, but the Wilcox Eocene, represented by the Pamunkey group, reappears farther north, within a few miles of the inner edge of the Coastal Plain in Virginia, Maryland, and Delaware.

Line 5.—The inner edge of the deposits of Claiborne Eocene age is shown by this line. The Claiborne sea was more restricted in extent than the Wilcox sea, and the Claiborne waters fell far short of reaching the head of the Mississippi Embayment. The deep southward indention of Line 5 in northeastern Texas and northwestern Louisiana, marks the position of the Sabine uplift, the axis of which is shown on the map. The Claiborne deposits were probably laid down over all of this area but were eroded away as a result of the uplift. They are almost overlapped by younger deposits in eastern Alabama, and, although revealed in places by erosion along drainage lines in Georgia and southwestern South Carolina, the area in which they occur in that State was completely transgressed by the next younger or Jackson sea. Claiborne deposits have not been identified either in surface outcrops or in wells anywhere in the Atlantic Coastal Plain north of South Carolina.

Line 6.—The inner edge of the Jackson, the youngest deposit of the Eocene, is shown by this line. It indicates a still greater restriction of the sea in the Gulf Coastal Plain in late Eocene time. However, a renewal of the downwarping in the Mississippi Embayment carried an arm of the Jackson sea at least as far north as had been reached by the Claiborne sea and perhaps a little farther. In the south Atlantic Coastal Plain a broad downwarp allowed the sea to sweep inland across all older deposits to the inner edge of the Coastal Plain in eastern Georgia and southwestern South Carolina. Farther north a broad upwarp having its axis near the boundary between North Carolina and South Carolina forced the Jackson strandline outward almost to the present coast, where the deposits of Jackson age may now be seen resting unconformably on the Upper Cretaceous. Farther north in North Carolina the Jackson deposits, represented by the Castle Hayne marl, pass under the Miocene and are not known anywhere in the North Atlantic Coastal Plain.

Line 7.—This line marks the inner edge of the Oligocene deposits which are represented by the Vicksburg group. In southern Texas the Oligocene deposits, as here interpreted, are completely overlapped by lower Miocene deposits, and are known only in wells. The line starts in eastern Louisiana

a few miles south of Line 6. Where it crosses Mississippi Valley the line is markedly convex to the north, but falls 200 miles short of reaching as far north as Line 6; apparently there was only slight downwarping in the Embayment during Oligocene time. Through eastern Mississippi and western Alabama Line 7 lies only a few miles south of Line 6. In eastern Alabama and western and central Georgia and Oligocene sea made a decided transgression to the north over the Eocene deposits, for Line 7 cuts obliquely across lines 6, 5, and 4, and in the vicinity of Macon the sea reached to within a few miles of the inner edge of the Coastal Plain. In eastern Georgia the Oligocene strata (Glendon chert) are in turn transgressed and concealed by Miocene deposits except in one relatively small area in Savannah River Valley, where erosion has uncovered them. No occurrences of Oligocene strata are known either in wells or outcrops anywhere in the Atlantic Coastal Plain north of the last mentioned area. The Catahoula sandstone of Mississippi, which has heretofore been correlated with the Oligocene, is believed by Doctors Wythe Cooke and Julia Gardner to be of lower Miocene (Aquitanian) age, and it seems probable that the Catahoula of Louisiana and Texas are also of lower Miocene age. It is on this assumption that Line 7 is not extended across Louisiana into Texas. Marine Oligocene representing the Vicksburg group has, however, been recognized in wells in southern Texas, showing that beds of this age are present there beneath younger beds.

Line 8.—Deposits of lower Miocene age are found inland as far as Line 8. In certain places these deposits carry marine fossils and were obviously laid down in marine waters of moderate depth. A considerable part of the deposits are, however, not of typical marine origin, but their distribution parallel to the coast suggests that their deposition was controlled by sea level. They were doubtless laid down in part in the shallow littoral waters of the sea, in part in bays, lagoons, and estuaries, in part in deltas, and in part as flood plain deposits on low plains bordering the sea. In determining the position of this line in Mississippi, Louisiana, and Texas, the opinions of Doctors Wythe Cooke and Julia Gardner, already cited, that the Catahoula sandstone in Mississippi belongs to the lower Miocene, is accepted. Some investigators regard this formation as Oligocene, and in Louisiana and Texas as contemporaneous in part with the Vicksburg group. In eastern Georgia the lower Miocene (Alum Bluff group) transgresses inland across Oligocene and Eocene formations to within 20 miles of the inner edge of the Coastal Plain, but in the southern part of South Carolina, Line 8, marking the inner edge of the Alum Bluff deposits, swings to the southeast and comes to the coast. North of this lower Miocene deposits have been recognized only in a limited area in eastern North Carolina (Trent marl), as indicated on the map. Apparently most of the Atlantic Coastal Plain north of South Carolina was above sea level and undergoing erosion in lower Miocene time. In Florida Line 8 outlines an island of upper Eocene deposits belonging to the Ocala limestone (of Jackson age) on the north, east, and south sides of which are overlapping deposits of lower Miocene age. This island-like area may once

have been covered by lower Miocene deposits which were later removed as a result of slight uplift and erosion.

Line 9.—This line, which marks the inner limit of deposits of upper Miocene age, shows a marked restriction of the sea of this time in the Gulf region as compared with the landward spread of all the earlier seas which participated in the upbuilding of the Gulf Coastal Plain. From southern Alabama westward the upper Miocene deposits were completely overlapped and concealed by the deposits of the next younger epoch, the Pliocene, and were later uncovered by erosion in the valleys only, in limited areas in southern Alabama, Mississippi, and Louisiana. Only relatively small areas in Florida and Georgia were covered by the waters of the upper Miocene sea, but from South Carolina northward to New Jersey there was marked transgression of the sea inland across the Atlantic Coastal Plain, the maximum submergence being in the northern part of North Carolina and in Virginia where the sea completely covered the Coastal Plain to its inner edge. In eastern South Carolina and southeastern North Carolina this upper Miocene transgression is indicated only by scattered erosion remnants of Miocene sediments occupying shallow depressions in the eroded surface of Upper Cretaceous deposits, but farther north the sheet of upper Miocene deposits is continuous, reaching a maximum thickness of several hundred feet.

Line 10.—This line marks the inner edge of deposits of Pliocene age. In the Gulf Coastal Plain these sediments are largely of non-marine origin, and were apparently laid down chiefly as coalescing alluvial accumulations on a low plain bordering the coast. In Mississippi and western Alabama these deposits (the Citronelle formation) spread northward across Miocene, Oligocene, and uppermost Eocene formations, but they are relatively thin, and the underlying overlapped formations are exposed by erosion in all except the smaller headwater valleys. A broken line is used to show this northward transgression of the Pliocene over older formations. The Pliocene is represented by marine deposits at a few localities in Florida and along the Atlantic Coast as far north as the southern part of North Carolina. These occurrences mark small embayments which extended a few miles inland. Mr. W. C. Mansfield has recently identified marine Pliocene marls along the shores of Neuse River south of New Bern, N. C. At many places on the higher interstream uplands of the Coastal Plain are erosion remnants of greater or less extent, of relatively thin surficial deposits of gravel, sand, and loam. These were laid down by ancient rivers which flowed across the Coastal Plain in meandering courses, probably during Pliocene time. They have never been mapped in detail and have been disregarded in the preparation of the accompanying sketch map.

Line 11.—This line marks the coastward limit of the outcrop of formations older than Pleistocene. Between this line and the coast only deposits of Pleistocene and Recent ages appear above sea level. This does not mean that these younger sediments are wanting on the landward side of the line, for on the contrary relatively thin terrace deposits of both marine and fluviatile

origin blanket the Tertiary and Cretaceous formations in extensive areas, in places extending back to and even beyond the inner edge of the Coastal Plain. The most widespread development of marine terrace deposits is in the Atlantic Coastal Plain and in Florida, and these record transgressions of the sea inland across the Coastal Plain in Pleistocene time. The most extensive sheets of alluvial terrace deposits occur in the valley of Mississippi River from the head of the Embayment to the Gulf, but terraced areas of lesser width occur in the valleys of all the larger streams crossing the Coastal Plain.

STRUCTURE

In general the strata composing the Coastal Plain lie in a gentle monoclinal attitude. They have been tilted seaward and, recalling the attenuated form of the cross-section of the sediments (fig. 1), the tilting was relatively slight, the dip rarely amounting to one degree, generally less than half and often less than a quarter of a degree, except in local structures. Slight as was the tilting it did not take place all at once but from time to time. In each tilting movement there was probably an axis of revolution parallel to the coast west of which the movement was upward and east of which it was downward. In general, but with certain exceptions, this axis advanced coastward with each successive tilting movement, and in this way formations that were laid down in the sea were later raised to various altitudes above the sea, reaching a maximum of 1,000 feet or more. Decrease of load in the area of denudation, and increase of load in the area of deposition have probably been the primary causes of the tilting, except in the New England area where the load of the Pleistocene ice doubtless was a major factor in completely submerging the Coastal Plain. Attention has already been called to the broad differential warping with axes at right angles to the trend of the Coastal Plain, which has resulted in the lobe-like overlapping of younger formations upon older. The approximate position of the axes of the folds in the principal areas of downwarping and upwarping are shown on the map. Where the transverse folding has taken place at different times the axes have not always been in exactly the same position. For example in the area of downwarping in eastern Georgia and southwestern South Carolina the axis in Eocene time lay approximately along the valley of Savannah River, as indicated on the map, whereas the axis of the downwarping which affected the same general area in early Miocene time lay farther west, approximately in the valley of Altamaha River. In addition to the general tilting and the broad transverse warping the Coastal Plain has been affected by minor folding and by many faults, ranging in size from short faults of small displacement to faults many miles in length

and several hundred feet displacement. The distribution of these faults is of interest. In the Atlantic Coastal Plain as far south as Georgia, faults are rare and the few that are known are of small displacement. Faults of some magnitude that we do not now suspect may lie concealed beneath some of the younger overlapping formations. The Charleston earthquake may have been caused by a movement along an active fault in the underlying basement rocks, and, if so, the overlying sediments were doubtless involved in the faulting. Charleston is on the north limb of one of the areas of broad downwarping. North of Cape Hatteras the down-warping in late Tertiary and in Quarternary times affected the Coastal Plain more completely than it did south of that point. The evidence for this appears first in the relatively small drowned valleys of eastern North Carolina, next in the more deeply drowned valleys of Chesapeake Bay and Delaware River, and finally in the completely submerged Coastal Plain off the coast of New England.

In Alabama faulting mostly of a small order of magnitude is abundant in the chalk near the top of the Cretaceous and in the basal formations of the Eocene. However, vertical displacements of as much as 300 feet have been reported in Wilcox County and one larger fault, the Jackson fault, over 15 miles long from north to south, and showing a maximum vertical displacement of 450 feet, lies just east of the east end of the Hatchetigbee anticline, the only large well formed anticline known east of Mississippi River in the Coastal Plain. The latter structure trends northwest-southeast in western Alabama about midway of the Coastal Plain from north to south, is 50 miles long by 20 miles wide, and exhibits a maximum uplift of 600 or 700 feet above the normal position of the beds involved in the folding. Some folding of the anticlinal nose and terrace types has been described in the vicinity of Jackson and Vicksburg in Mississippi, and minor faulting and some reversals of dip are also known in the State. The New Madrid earthquake in the northern part of the Mississippi Embayment is believed to have been due to faulting in the underlying basement rocks, and it is reasonable to suppose that these movements caused breaks and displacements in the overlying Coastal Plain sediments.

As we go westward in the Gulf Coastal Plain evidence of former crustal unrest becomes more pronounced. The intensive work of geologists in the past few years in connection with the development of petroleum resources has brought to light a multitude of faults both small and large in southwestern Arkansas, northern Louisiana, and in Texas, especially in the Upper Cretaceous and lower Tertiary forma-

tions. The Balcones fault zone which extends from north of Austin, southwestward to San Antonio, and westward toward the Rio Grande, and which manifests itself in the present topography as well preserved fault scarps, has long been known. The more important vertical displacements along this fault zone range from 500 to 1,000 feet. The latest pronounced movements in this zone are probably of early Pliocene age. There is in the Texas Coastal Plain another zone of faulting, the existence of which was scarcely suspected until a few years ago, when it was discovered as a result of the intensive study of structural conditions carried on in connection with oil developments. This zone is long and narrow and parallels the Balcones fault zone at a distance of 10 to 15 miles, from Uvalde County south of Uvalde, to Travis County east of Austin. North of Travis County no important faults have been discovered along the trend of the zone in Williamson and Milam counties, but from Falls County northward the zone is continued in many pronounced faults, and it is there known as the Mexia-Powell fault zone. In northeastern Texas the zone bends to the eastward and passes out of Texas into southwestern Arkansas. The zone is almost coextensive with the outcrop of the Midway or basal formation of the Eocene, involving, however, the strata of the underlying Cretaceous and the overlying Wilcox divisions. In contrast to the Balcones faults, the faults in this zone are with rare exceptions scarcely discernible at the surface, due to the fact that erosion has obliterated whatever scarps may have been produced by the faulting. This would seem to show that this zone is older than the Balcones zone, many of whose fault scarps still remain well preserved. Although several of the faults of this greatly attenuated zone had previously been recognized, the game of finding them did not begin in earnest until one of them, discovered in drilling the Mexia oil field, was found to provide the essential conditions for the accumulation of oil. The faults are of all lengths up to 25 miles or more, and the displacements range from a few feet to over 600 feet. In general the faults are arranged *en-echelon* along the zone of faulting, though the trend of most of them makes only a small angle with the trend of the zone. Some of the faults lie almost parallel to each other for long distances. The downthrow of most of the faults is to the west or northwest, though some of them are downthrown to the east or southeast, and several pairs of faults are known to form definite grabens. Commercial quantities of oil have been found on the upthrow side of 7 or 8 of the faults whose downthrow is to the west. The Mexia, Powell, Wortham, and Luling fields are the most notable examples.

The faults of the Texas Coastal Plain are by no means confined to the two main zones of faulting just described, for a goodly number of faults, whose systematic arrangement has not as yet been determined, have been recognized in other parts of the area. In addition to the faults there are several well defined anticlinal folds mostly along or near the margin of the Coastal Plain, such as the Preston anticline, the Leonard-Celeste anticlinal nose, and several folds between San Antonio and the Rio Grande. Probably most of the faults and folds are related to structural movements in the underlying basement rocks.

One of the fascinating features of Gulf Coastal Plain geology, fascinating because of the difficulty of explaining it, is the phenomenon of salt domes. The domes, of which 70 or more are known, are scattered over a wide area in Texas and Louisiana. A few manifest themselves clearly at the surface, but many lie completely buried and hidden. They consist of plugs of salt, ranging in diameter from 1 mile to 3 miles or more, driven like nails in a plank, upward through thousands of feet of Coastal Plain sediments, dragging with them, or pushing ahead of them, fragments of deeply buried formations. In one instance a block of Buda limestone, the uppermost of the Comanche Cretaceous formations, was raised from its normal position of over 5,000 feet below the surface to the surface, as shown by the record of a nearby well. The origin of the salt is still a matter of speculation, though most geologists believe it has been squeezed upward through points of structural weakness, by the weight of surrounding strata, from deeply buried masses of salt of Permian or perhaps of Trinity Cretaceous age. Wells have been drilled to depths of more than a mile in the salt and no well has completely penetrated it. The salt domes of southeastern Texas and southern Louisiana are of particular economic interest because of the occurrence of oil and gas in the sediments surrounding and overlying them.

The increase in structural complexity so noticeable in passing westward in the Gulf Coastal Plain becomes far more pronounced beyond the international boundary in Mexico. Comparable to the Balcones fault zone in its geologic relations is the great zone of faults along the eastern front of the Mesa Central which stands 2,000 to 7,000 feet or more above sea level. In the latter zone, as in the former, the strata of the Upper Cretaceous are downthrown on the east against upthrown limestones of the Lower Cretaceous on the west. But whereas the vertical displacements in the former may be measured in hundreds of feet, in the latter they amount to thousands of feet. In the Balcones zone, small erosion remnants of Upper Cretaceous strata still remain

in places on the Edwards Plateau near its southern margin some 1,100 feet or more above sea level, but in Mexico, notably in the State of San Luis Potosí, great masses of Upper Cretaceous strata have been raised 4,000 feet or more above sea level. The great tract of relatively low country, sometimes referred to as the Huasteca region, which lies between the foot of the eastern front of the Mesa Central and the Gulf Coast, is comparable to the Texas Coastal Plain in that it is composed of Cretaceous and Tertiary sedimentary rocks of the same age and origin, and some of the low-lying country along the coast, and in places extending for considerable distances back from the coast, may rightly be classed as Coastal Plain. But in contrast to the Texas Coastal Plain a large part of this area has been subjected to pronounced folding and faulting, and many hills and ridges and several mountains of no mean size rise above the general lowland. Among the latter may be mentioned the San Carlos, the Tamaulipas, and the Otontepec Mountains. There is also one long fault block mountain range which in early and middle Eocene time stood well above sea level, but which later sank far below sea level and is now completely buried under some 2,000 feet of later Tertiary sediments. This is the great South Fields structure, the Golden Lane, from which prodigious quantities of oil have been recovered. Intrusions of igneous rock, in the form of dikes and larger masses, are also common in many parts of this area. The several greatly elongated structural features, such as the Balcones fault zone, the long line of faulting of which the Mexia-Powell fault zone forms a part, the faulted eastern front of the Mesa Central, the line of structures, including the San Carlos and Tamaulipas Mountains, and the buried structure of the south fields in Mexico, all of which roughly parallel the Coast, seem definitely related to the great geosynclinal basin of the Gulf of Mexico. These features of fracture and folding are generally explained as due to overloading and downsinking in this basin; but downsinking is by no means the complete explanation of the faulting. Back of the great fault zones, in the Edwards Plateau and the Great Plains, in the Rocky Mountain region, and in the Mesa Central, great masses of sedimentary rocks formed in marine waters below sea level have not gone down, but instead have been subjected to positive upward movements which have raised them from 1,500 to 5,000 feet or more above sea level.

Briefly reviewing the structure, we have in the Atlantic and eastern Gulf Coastal Plain a gentle monocline with all formations from Cretaceous to Recent included in the Coastal Plain itself. In Texas this monocline has been split by the Balcones faulting and part of the

Cretaceous sediments, chiefly Lower Cretaceous, have been raised to form the Edwards Plateau, too high to be classed with the Coastal Plain. In Mexico Cretaceous sediments, both Lower and Upper, have been raised back of a fault zone which may be regarded as analogous to the Balcones fault zone, to altitudes several times higher than the Edwards Plateau, to form part of the plateau of the Mesa Central. In front of this fault zone a great area of Cretaceous and Tertiary sediments comparable in many ways to those of the Texas Coastal Plain have been folded, faulted, and uplifted into minor mountain masses, in such manner as to exclude them from the Coastal Plain.

THE FOSSIL FLORAS AND FAUNAS

The subject of the fossil floras and faunas of the Coastal Plain is too big a one for even summary treatment in this paper. Fossil plants and animals occur well distributed in the sediments, both geographically and geologically. The fossil plants are found in both the shallow marine and non-marine sediments along and adjacent to the old shore lines, and the shifting of the shore lines has provided the conditions for the preservation of plants here and there in the sediments of the several periods from the Cretaceous to the Pleistocene. But the record afforded by fossil plants is very incomplete. Marine invertebrates are much more completely represented than other classes of organisms, because sediments of marine origin greatly predominate over those of non-marine origin, and also because the conditions of marine sedimentation are more favorable for the preservation of fossil remains. The bones and teeth of vertebrates are found fairly well distributed through the formations of the Coastal Plain but, with few exceptions, are fragmental and incomplete, and while of interest as showing the geologic distribution of vertebrates, they have been of little use in solving the finer problems of stratigraphy and correlation.

In general there have been progressive changes in the character and composition of the floras and faunas from early Cretaceous to Recent time. Evolutionary development has been constantly taking place, species, genera, and even great groups of organisms have become extinct, and new forms have occasionally entered the area by migration from other regions. It is on the basis of such changes that the time relationships of the formations are determined from place to place in the Coastal Plain, and on the same basis sediments of the Coastal Plain are correlated more or less successfully with those of other parts of the continent and of the world. One of the chief difficulties met with in determining the age relationships of the formations of the Coastal Plain by means of fossils is the differences in contemporaneous

faunas due to differences in the ecological conditions under which they lived. Many marine species were restricted to rather definite sets of environmental conditions, so that their fossil remains are not found everywhere in beds of the same age. Fortunately, however, there were also a goodly number which were able to adapt themselves to wider variations, and we find their fossil remains in different kinds of sediments of the same age, as for example, in sands, clays, marls, and chalks, and we are thus able to trace fossil zones through different kinds of sediments.

Of the two classes of fossil organisms, plants and invertebrate animals, it can scarcely be denied that the invertebrates afford the more accurate basis for determining time relationships. Some of the conflicting conclusions arrived at by the application of the two classes of criteria may be due to the tendency on the part of invertebrates to respond more promptly and more definitely, in an evolutionary sense, to changing environmental conditions than do plants. Certain it is that the correlations made on the basis of plants are not always in agreement with those determined by the animal evidence. One of the most striking examples of apparent disagreement is that of the flora of the Ripley formation of northern Tennessee, which, as interpreted, is of the age of the Emscherian, or possibly as young as the overlying Campanian of Europe, whereas the evidence afforded by invertebrate fossils indicates that the Emscherian is represented in the Coastal Plain, not by the Ripley, but by the much older Eutaw formation in the eastern Gulf region, and by the Austin chalk in the western Gulf region, both occupying stratigraphically lower positions than the Ripley. The Ripley plant-bearing beds according to the invertebrate evidence should be correlated with either the uppermost Campanian or with the Maestrichtian, both of which zones are much younger than the Emscherian. This is not intended to belittle the importance of fossil plants in stratigraphy, for the evidence afforded by plants is by no means always in disagreement with that afforded by invertebrates. Fossil plants are especially valuable in correlating irregularly-bedded shallow-water sediments in which invertebrates are rare or wanting.

The record of the organisms that lived in the Coastal Plain during Cretaceous and later time is incomplete even in the marine sediments, for some forms do not lend themselves to preservation, conditions for preservation are less favorable in some kinds of sediments than in others, and there are gaps in the record marking the times when the sea retreated and land conditions prevailed. These gaps are the unconformities, some of which have already been mentioned, and the

more intensive studies of the past twenty years have shown that there are many more of these unconformities than was formerly suspected. The fossil faunas in the sediments above the unconformities are nearly always different from those in the sediments below, and the magnitude of the differences may, with certain limitations, be taken as a measure of the time represented by the unconformities. Any given unconformity should extend coastward into the buried sediments as far as the strand line retreated at the time the unconformity was formed. Beyond that line there should be no break in the succession. Therefore the farther seaward one goes the more complete should be the succession of sediments. Among the many unconformities that have already been recognized in the sediments of the Coastal Plain, there is one which is of preeminent importance. This is the unconformity which separates the Cretaceous from the Eocene. The strand line may have retreated as far as the edge of the Continental Shelf itself. The time represented is believed to have been of great duration. During this time some important changes took place in the character of the organisms inhabiting the sea. Of mollusks, for example, not a single species is known with certainty to have survived from Cretaceous to Eocene time. Although many Cretaceous molluscan genera are represented in the Eocene by new species, descendants of the earlier species, a long list of genera that became extinct at the end of the Cretaceous may be enumerated, and among these may be mentioned one whole order, the *Ammonoidea*, represented by numerous genera. This great unconformity is not confined to our Coastal Plain, nor even to our continent, but appears to be almost world-wide, at least so far as marine sedimentation is concerned, and constitutes an important gap in the record of the marine life of the earth.

CLIMATE

In general the climatic conditions along the Atlantic and Gulf Coastal Plain during Cretaceous and most of Tertiary time, were mild, that is warm temperate to subtropical, and there was no sharp separation into climatic zones. Evidence for close approximation to uniformity in temperature and other living conditions throughout the Coastal Plain in Upper Cretaceous time is clear and positive. This evidence is afforded by the relatively large number of molluscan species that were able to range throughout the area during any given epoch. Emphasis should, however, be placed on the fact that there are also a large number of other species that were not so cosmopolitan in their range. Notwithstanding the close approach to uniformity there were

evidently conditions, probably both climatic and environmental, that limited the geographic range of many of the species. The waters of the Gulf were certainly a little warmer and more tropical than those of the Atlantic during Cretaceous, Eocene, Oligocene, and lower Miocene time, as is shown by the great accumulations of chalk and limestone in the Gulf, and by certain of the fossil organisms. The Chamacea and Rudistacea, for example, which were fairly common in the waters of both of the Lower and Upper Cretaceous in the Gulf, apparently did not venture farther north than Alabama; the larger foraminifera which are abundant in parts of the Eocene and Oligocene, ranged only as far north as the southernmost part of South Carolina,[2] and the molluscan faunas of the Tertiary as high as the lower Miocene contain many tropical elements which did not range far northward along the Atlantic coast. Toward the latter part of Tertiary time a decided climatic change took place along the Atlantic border, as indicated by the cooler water faunas of the Chesapeake, or upper Miocene, which ranged as far south as northern Florida. This may be regarded as foreshadowing the still colder climate of the Pleistocene. The entire Atlantic and Gulf Coastal Plain undoubtedly felt the chill of the Pleistocene glaciers, most in the north, least in the south, but the only places where the ice sheet touched the Coastal Plain were along the southern coast and islands of New England, on Long Island, and in northern New Jersey.

PROBLEMS OF COASTAL PLAIN GEOLOGY

The distribution of the geological formations throughout most of the Coastal Plain has been determined with sufficient accuracy for representation on maps of 1:1,000,000, or even 1:500,000 scale. Comparatively small parts of the area have, however, been mapped in sufficient detail to satisfy the standards of the folio publications of the Geological Survey. Great progress has been made in determining the stratigraphic relationships of the formations, but in every Coastal Plain state there are still unsolved problems in stratigraphy which call for detailed field investigations and systematic studies of the fossil faunas and floras. Hundreds of species still remain to be described, and much is yet to be learned about the environmental conditions under which the faunas and floras lived, and the causes of their changes, migrations, and extinctions.

The remarkable progress that has been made in the past few years in the discovery of structural features in the Gulf Coastal Plain, where the strata had always been supposed to lie mainly in simple monoclinal attitude, may be taken as a prophesy of the discovery of many more

[2] Oral communication from Dr. Wythe Cooke.

such features as intensive search for them proceeds. Many of these features developed in the older formation are completely concealed by overlapping younger formations and can only be recognized by means of well data, and even the structural features which lie at the surface are in places so effectually obscured by the similarity of materials composing adjacent formations of different ages, and by deep weathering and deep soils, that they can only be discovered by detailed and painstaking study. There is need for more definite criteria for determining the origin of different kinds of marine and non-marine sediments. Were they deposited on alluvial plains bordering the coast; were they deposited off the mouths of rivers, and how far off; or were they drifted along shore for greater or less distances before coming to their final resting place on the ocean bottom? Light-colored irregularly bedded sands and clays, such as the Tuscaloosa and Wilcox formations, are not uncommonly assigned to continental origin, yet some such formations were certainly laid down in whole or in part in shallow lagoons, bays, and even in the shallow waters of the sea itself. To what extent are the sediments made up of material derived by chemical precipitation from sea water? In short, the mechanical, chemical, and biological processes involved in the formation of sediments are so far from being completely known that they present fascinating fields of research to future investigators. There is yet much to be learned about the changes in sea level, the warping of the land, the consequent transgressions and recessions of the sea, and the unconformities in the sediments which record these movements; it is safe to predict that many more unconformities will be found in the sediments of the Coastal Plain than are now known. There are interesting problems relating to the origin of the extensive blankets of surficial deposits that cover so much of the Coastal Plain, problems that call for years of intensive study, for there are many divergent opinions about them. There are many economic problems in connection with the non-metallic mineral resources of the Coastal Plain, for the area abounds in raw materials that will some day be developed far more extensively than they are at present—gravel, sand, clay, marl, chalk, bauxite, peat, lignite, and ground waters, not to mention the vast amounts of petroleum and natural gas which doubtless still remain to be discovered in the Gulf Coastal Plain. The discoveries of the past 15 years have shown that, with future more intensive studies, many new and interesting features of structure, stratigraphy, lithology, and paleontology, and many additional raw materials of economic value, are certain to be discovered, so that extensive as have been the investigations of the past, the Coastal Plain still remains an attractive field for geologic, paleontologic, and economic research.